Increased Muscle Size and Strength From Slow-Movement, Low-Intensity Resistance Exercise and Tonic Force Generation

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The authors investigated the effects of low-intensity resistance training on muscle size and strength in older men and women. Thirty-five participants (age 59–76 yr) were randomly assigned to 2 groups and performed low-intensity (50% of 1-repetition maximum) knee-extension and -flexion exercises with either slow movement and tonic force generation (LST; 3-s eccentric, 3-s concentric, and 1-s isometric actions with no rest between repetitions) or normal speed (LN; 1-s concentric and 1-s eccentric actions with 1-s rests between repetitions) twice a week for 12 wk (2-wk preparation and 10-wk intervention). The LST significantly increased thigh-muscle thickness, as well as isometric knee-extension and -flexion strength. The LN significantly improved strength, but its hypertrophic effect was limited. These results indicate that even for older individuals, the LST can be an effective method for gaining muscle mass and strength.

Keywords: muscle hypertrophy, sarcopenia, aging

Sarcopenia, defined as the aging-related loss of muscle mass (Evans, 1995), results in a loss of strength and leads to a successive impairment of basic locomotor function. In older individuals, the loss of muscle strength has been shown to be a primary factor of frailty, falls, and loss of independence (Wolfson, Judge, Whipple, & King, 1995). Therefore, preventing sarcopenia is important to maintain the quality of life of older individuals.

Resistance training with moderate to high intensity (~80% one-repetition maximum [1RM]) has been extensively used to increase muscle mass and strength, while that with an intensity lower than 65% 1RM is considered less effective (McDonagh & Davies, 1984). The importance of training intensity has been thought to be consistent across age, as well as sex. In fact, some studies have shown that high-intensity
resistance training successfully induced muscle hypertrophy and strength gain in older adults (Fiatarone et al., 1990; Frontera, Meredith, O’Reilly, Knutgen, & Evans, 1988; Harridge, Kryger, & Stensgaard, 1999). However, strenuous exercise with large mechanical stress may be associated with a risk of orthopedic injury. Pollock et al. (1991) demonstrated that approximately 20% of older adults (age 70–79 years) showed some symptoms of orthopedic injury after exercise at 1RM. In addition, a marked increase in systolic blood pressure (up to >250 mm Hg) occurred during high-intensity resistance exercise (~8RM) for large muscle groups (Fleck, 1988).

Although the effect of resistance training with low to moderate intensity has been studied for older individuals, the increase in muscle size is limited (Aniansson & Gustafsson, 1981; Moritani & deVries, 1980; Taaffe, Pruitt, Pyka, Guido, & Marcus, 1996) or much smaller than that induced by a high-intensity resistance training (Kalapotharakos et al., 2004). However, recent studies showed that relatively low-intensity (50–60% 1RM) resistance training caused significant increases in muscle size and strength, as did traditional high-intensity (80–90% 1RM) resistance training, in young untrained men (Tanimoto & Ishii, 2006; Tanimoto et al., 2008). The exercise method they used is called low-intensity resistance exercise with slow movement and tonic force generation (LST) that is characterized as slow movement and tonic force generation (sustained contractile force with continuous electromyographic activity of working muscle). Since this type of exercise is not associated with the generation of large accelerating and decelerating force and undesirable elevation of blood pressure (Tanimoto & Ishii, 2006), LST can be a useful intervention, especially for older individuals.

Thus, the current study investigated a chronic effect of LST on muscle size and strength in older men and women. In addition, muscle oxygenation level and blood lactate and hormone concentrations were measured during and after a single bout of LST to see if the LST protocol causes acute physiological responses in older participants similar to those reported for young participants (Goto, Takahashi, Yamamoto, & Takamatsu, 2008; Tanimoto & Ishii, 2006; Tanimoto, Madarame, & Ishii, 2005; Tanimoto et al., 2008).

**Methods**

**Participants**

Forty healthy older men and women (59–76 years of age) who were active and did not engage in regular resistance exercise were recruited. They volunteered as participants after a medical screening. None of them had coronary risk factors, symptoms of cardiovascular disease, definite osteoporosis risk for compression fracture, uncontrollable hypertension, or any other medical problems associated with participation in the study. All participants were fully informed about the experiment procedures and the purpose of the study and gave written informed consent before participation. The study was approved by the local ethics committee.

**Resistance-Training Procedure**

The participants in each training group performed low-intensity (50% 1RM) resistance exercises for knee extension and knee flexion with isotonic resistance-exercise machines (seated knee-extension machine, Galaxy Sport, Germany, and
seated knee-flexion machine, Life Fitness, USA). The range of knee-joint motion was 0–90° (0° represents full extension) in knee-extension exercise and 10–100° in knee-flexion exercise. The participants were randomly assigned to two experimental groups. One group \((n = 21)\) exercised with the LST method (3-s eccentric, 3-s concentric, and 1-s isometric actions with no rest between repetitions). The other group \((n = 19)\) exercised at normal speed (1-s concentric and 1-s eccentric actions with 1-s rests between repetitions, LN group). Participants in both groups repeated the movement at approximately constant speed and frequency with the aid of a metronome. In this study, we matched the intensity of exercise and the work volume (total repetition) to make the LST and LN protocols different only with respect to exercise movement. The exercise session consisted of three sets of eight repetitions with rest periods between sets of 60 s. The participants performed knee-extension exercise and then knee-flexion exercise, with a 5-min rest period between exercises. The exercises were performed twice a week for 12 weeks (2-week preparation and 10-week intervention). The exercise intensity was 50% 1RM, which was tested every 4 weeks. The initial 2 weeks served as a preparation period during which the participants gradually increased exercise intensity and volume (40% 1RM × 2 sets for the first week; 45% 1RM × 2 sets for the second week).

**Measurement of Blood Lactate Concentration**

Blood lactate concentration was measured before and after a single bout of exercise during 7–9 weeks of the intervention period. Blood samples were collected before, immediately after the knee-extension exercise, and immediately after the knee-flexion exercise. A preexercise blood sample was obtained after a 10-min rest (sitting on a chair). Approximately 5 μl of blood was taken from the fingertip by using a disposable lancet and immediately analyzed for lactate concentration with a lactate analyzer (Lactate Pro, Arkray, Kyoto, Japan).

**Measurement of Muscle Thickness**

The muscle thickness of both front (knee extensors) and back (knee flexors) portions of the left thigh was measured by B-mode ultrasound imaging, in which the experimenter was not aware of group allocation. The muscle thickness was measured before the 2-week preparation period and after the 10-week intervention. The measurements were made while the participants stood. The measurement position was the midpoint between the lateral epicondyle of the femur and the greater trochanter. Transverse images were obtained using a real-time linear electronic scanner with a 7.5-MHz scanning head (SSD-500, Aloka, Japan). The scanning head was pretreated with water-soluble transmission gel that provided acoustic contact without compressing the skin surface. The measurements were repeated three times for each portion, and the median of the three values used for analysis. The intraclass correlation coefficient and the mean coefficient of variance for the repeated measurements were .998 and 3.7%, respectively.

**Measurement of Muscle Strength**

Muscle strength was evaluated with a 1RM test and isometric muscle-strength test. The 1RM was defined as the largest weight the participants could lift one time only through a full range motion without noticeable countermovement. Muscle strength
was measured before the 2-week preparation period and after the 10-week intervention. 1RM was determined as follows: The participant performed each exercise several times at low to high intensity (approximately 50% 1RM × four to six times and 75–85% 1RM × two to four times) as a familiarization. After familiarization, the participant tried to lift the previously determined 1RM (or the estimated 1RM for the initial test). The weight of trial was then increased by 1.25–5.0 kg in a stepwise manner until the participant could not lift the weight (the determination of 1RM typically required two or three trials). A 2-min recovery period was allowed between trials.

The maximal isometric torque of knee extension and knee flexion was measured with an isokinetic dynamometer (Cybex RZ-450, Cybex, USA), in which the experimenter was not aware of group allocation. After a brief leg-muscle stretching (approximately 15 s), participants sat on a chair with their back upright and with their left leg (nondominant side) firmly attached to the lever of the dynamometer. A pivot point of the lever was accurately aligned with the rotation axis of the knee joint, and the requisite axial alignment of joint and dynamometer axes was maintained during the movement. The isometric peak torque for both knee extension and flexion was measured at a knee angle of 60°. After the participants were familiarized with the test procedure, two trials at maximal effort were made with a 2-min recovery period, and the greater value obtained was used for analysis.

**Acute Changes in Muscle Oxygenation and Blood Hormones**

Acute physiological responses such as muscle oxygenation level and blood hormone concentrations during and after a single bout of exercises are thought to influence chronic muscle adaptation (Tanimoto & Ishii, 2006; Tanimoto et al., 2008). After the completion of the 10-week intervention period, we thus measured changes in muscle oxygenation level and blood hormone concentrations in response to a single bout of exercises that were assigned to each participant during the intervention. Muscle oxygenation level was measured 1–4 weeks after the intervention period for 16 men and 15 women who completed the 10-week intervention program. Blood hormone concentrations were measured 5–6 weeks after the intervention period for 14 men and 14 women who completed the 10-week intervention. Fourteen men and 13 women participated in both measurements.

Near-infrared continuous-wave spectroscopy (NIRcws) was used to measure the oxygenation level in the left vastus lateralis muscle during and after the knee-extension exercise (BOML1TR, Omegawave Inc., Japan). The wavelengths of emission light were 780, 810, and 830 nm, and the relative concentrations of oxygenated hemoglobin and myoglobin (Oxy-Hb/Mb) in tissues were quantified according to the Beer-Lambert law (Chance, Dait, Zhang, Hamaoka, & Hagerman, 1992). Because the NIRcws signals detected during exercise do not always reflect the absolute levels of oxygenation, the muscle oxygenation level were expressed relative to the overall changes in the signal obtained according to the arterial occlusion method (Chance et al., 1992; Hampson & Piantadosi, 1988). In the current study, the resting level of Oxy-Hb/Mb was defined as 100% (baseline), and the minimum plateau level of Oxy-Hb/Mb after arterial occlusion was defined as 0%. A pressure cuff was placed around the proximal portion of the thigh and manually inflated up to 300 mm Hg until the minimum plateau level of Oxy-Hb/Mb was obtained (Bae et al., 2000). The distance between the incident point and the detector was 30 mm. The laser emitter and detector were fixed with sticky tape after being shielded...
with a rubber sheet. The NIRcws signals were stored on a personal computer with a data-acquisition system (Mac Laboratory/4S, AD Instruments, USA). In this study, the minimal muscle oxygenation level during exercise and the maximal muscle oxygenation level after exercise were examined as dependent variables.

For the measurement of blood hormone concentration, the participants refrained from ingesting alcohol and caffeine for 24 hr and performing any strenuous exercise for 48 hr before the exercise. Venous blood samples (10 ml for each point of measurement) were taken from the antecubital vein in a seated position. A preexercise blood sample was obtained after 30 min of rest. The exercise session started 15 min after the resting blood sample was taken. After the exercise session, blood samples were obtained 0 min (immediately after the exercise) and 20 min after the exercise and then analyzed for serum growth hormone, plasma noradrenaline, and cortisol. Serum samples were stored at 4 °C and plasma samples were stored at −20 °C until analysis. Serum and plasma samples were obtained by 10-min centrifugation at 3,000 rpm. Concentrations of growth hormone, noradrenaline, and cortisol were determined using immunoradiometric assay, high-performance liquid chromatography, and radioimmunoassay, respectively. Intra-assay coefficients of variance in these measurements were <5.0%.

Statistical Analysis

All values are expressed as $M \pm SD$. Three-way analysis of variance (ANOVA) with a Holm post hoc procedure (Chan et al., 2007) was used to examine main effects of sex, group, and time and their interactions in all variables except muscle oxygenation level. However, none of the interaction terms that included sex was statistically significant. Therefore, for all outcome variables we report the findings from two-way ANOVAs testing the effects of group and time and their interaction. For testing the effects of sex and group and their interaction in muscle oxygenation level, two-way ANOVA with a Holm post hoc procedure (Chan et al., 2007) was used. Differences between two variables in the same group were examined with Student’s paired $t$ test. For all statistical tests, in which $p < .05$ was considered significant, the exact $p$ value was reported with an effect size of $\eta_p^2$ (ANOVA) and $r$ ($t$ test).

Results

Five participants could not finish the training program, so data from 35 participants (17 men and 18 women) who completed the program were used for the analysis (Table 1). Individuals withdrew from the study for following reasons: injury

<table>
<thead>
<tr>
<th>Variable</th>
<th>Low-intensity resistance exercise with slow movement and tonic force generation ($n = 18$)</th>
<th>Low-intensity resistance exercise with normal speed ($n = 17$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>$66.8 \pm 3.8$</td>
<td>$66.8 \pm 5.2$</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>$158.3 \pm 6.6$</td>
<td>$158.6 \pm 8.5$</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>$59.8 \pm 6.6$</td>
<td>$61.0 \pm 9.1$</td>
</tr>
</tbody>
</table>
unrelated to the training intervention (1 man and 1 woman), illness (2 women), and work (1 man). The exercise adherence rate in this study was 87.5% (35/40). No significant differences between groups were found for physical characteristics, thigh-muscle thickness, or muscle strength (1RM and isometric strengths) before 2-week preparation period.

**Blood Lactate Concentration**

Figure 1 shows changes in blood lactate concentration measured at rest and immediately after a single bout of exercise with the LST and LN protocols. Two-way ANOVA revealed significant main effects for group, $F(1, 66) = 76.575, p < .001, \eta_p^2 = .537$, and time, $F(2, 66) = 158.925, p < .001, \eta_p^2 = .828$, which were superseded by a significant interaction of group by time, $F(2, 66) = 22.006, p < .001, \eta_p^2 = .400$. In both LST and LN groups, the blood lactate concentration significantly increased after the knee-extension exercise (LST, $p < .001, r = .95$; LN, $p < .001, r = .89$) and the knee-flexion exercise (LST, $p < .001, r = .95$; LN, $p < .001, r = .90$) from that at rest. The mean values of blood lactate concentration immediately after the exercise in LST group were significantly higher than after exercise in LN group (knee-extension exercise: $p < .001, r = .59$; knee-flexion exercise: $p < .001, r = .66$), despite the same intensity and mechanical work in the two groups.

**Changes in Muscle Thickness**

Table 2 shows the changes in MT of front and back portions of the thigh. In the front muscle thickness, two-way ANOVA revealed no significant main effect for group, $F(1, 33) = 0.024, p = .878, \eta_p^2 < .001$, and a significant main effect for time, $F(1, 33) = 8.864, p = .005, \eta_p^2 = .212$, which were superseded by a significant interaction of group by time, $F(1, 33) = 5.898, p = .021, \eta_p^2 = .152$. The front muscle thickness significantly increased after LST training ($p < .001, r = .67$), whereas no such change was observed after LN training ($p = .731, r = .09$). The change in the

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**Figure 1** — Changes in blood lactate concentrations before and immediately after exercises with slow movement and tonic force generation (filled, $n = 18$) and normal speed (open, $n = 17$), $M \pm SD$. Ex = extension; flex = flexion. *$p < .05$; significant difference between pre- and postexercise. †$p < .05$; significant difference between groups.
front muscle thickness was significantly larger in the LST group than in the LN group \( (p = .038, r = .39) \).

In the back muscle thickness, two-way ANOVA revealed significant main effects for group, \( F(1, 33) = 16.762, p < .001, \eta^2_p = .337 \), and time, \( F(1, 33) = 12.270, p = .001, \eta^2_p = .271 \), which were superseded by no significant interaction of group by time, \( F(1, 33) = 0.636, p = .431, \eta^2_p = .019 \).

### Changes in Muscle Strength

Table 3 shows the changes in 1RM and isometric strength for knee-extension and knee-flexion exercises. In the knee-extension 1RM, two-way ANOVA revealed no significant main effect for group, \( F(1, 33) = 0.408, p = .527, \eta^2_p = .012 \), and a significant main effect for time, \( F(1, 33) = 62.809, p < .001, \eta^2_p = .656 \), which were superseded by no significant interaction of group by time, \( F(1, 33) = 0.048, p = .829, \eta^2_p = .001 \). In the knee-flexion 1RM, two-way ANOVA revealed no significant main effect for group, \( F(1, 33) = 0.002, p = .964, \eta^2_p < .001 \), and a significant main effect for time, \( F(1, 33) = 128.495, p < .001, \eta^2_p = .796 \), which were superseded by no significant interaction of group by time, \( F(1, 33) = 1.449, p = .237, \eta^2_p = .042 \).

In knee-extension isometric strength, two-way ANOVA revealed no significant main effect for group, \( F(1, 33) = 2.569, p = .119, \eta^2_p = .072 \), and a significant main effect for time, \( F(1, 33) = 18.909, p < .001, \eta^2_p = .364 \), which were superseded by no significant interaction of group by time, \( F(1, 33) = 1.304, p = .262, \eta^2_p = .038 \). In knee-flexion isometric strength, two-way ANOVA revealed significant main effects for group, \( F(1, 33) = 6.295, p = .017, \eta^2_p = .160 \), and time, \( F(1, 33) = 78.980, p < .001, \eta^2_p = .705 \), which were superseded by no significant interaction of group by time, \( F(1, 33) = .955, p = .336, \eta^2_p = .028 \).

### Muscle Oxygenation Level

Figure 2 shows minimal and maximal oxygenation levels in the left vastus lateralis muscle during and after the knee-extension exercise with the LST and LN protocols. In both groups, the muscle oxygenation level showed a gradual decrease during the exercise and a rapid recovery followed by an overshoot after the exercise. In the minimal oxygenation level during exercise, two-way ANOVA revealed a significant main effect for sex, \( F(1, 27) = 10.608, p = .003, \eta^2_p = .282 \), and no significant main effect for group, \( F(1, 27) = 0.545, p = .467, \eta^2_p = .020 \), which were superseded by...
no significant interaction of sex by group, $F(1, 27) = 0.730, p = .400, \eta_p^2 = .026$. No significant difference was observed in the minimal oxygenation level between LST and LN groups.

In the maximal oxygenation level after exercise, two-way ANOVA revealed no significant main effect for sex, $F(1, 27) = 1.644, p = .211, \eta_p^2 = .045$, and a significant main effect for group, $F(1, 27) = 6.479, p = .017, \eta_p^2 = .156$, which were superseded by no significant interaction of sex by group, $F(1, 27) = 0.004, p = .952, \eta_p^2 < .001$. The maximal oxygenation level was significantly higher in LST than in LN ($p = .018, r = .42$; Figure 2).
Blood Hormone Concentrations

Figure 3 shows changes in concentrations of serum growth hormone, plasma noradrenaline, and plasma cortisol measured at rest and after exercise in the LST and LN protocols. In the concentrations of serum growth hormone, two-way ANOVA revealed significant main effects for group, $F(1, 52) = 16.745, p < .001, \eta^2_{p} = .244$, and time, $F(2, 52) = 4.472, p = .016, \eta^2_{p} = .147$, which were superseded by no significant interaction of group by time, $F(2, 52) = 0.472, p = .627, \eta^2_{p} = .018$. In the concentrations of plasma noradrenaline, two-way ANOVA revealed significant

Figure 3 — Changes in concentrations of serum growth hormone, plasma noradrenaline, and cortisol before and after exercises with slow movement and tonic force generation (filled, $n = 15$) and normal speed (open, $n = 13$), $M \pm SD$. pre = preexercise; post = immediately after exercise; 20 min = 20 min after exercise.
main effects for group, $F(1, 52) = 50.220, p < .001, \eta_p^2 = .491$, and time, $F(2, 52) = 28.278, p < .001, \eta_p^2 = .521$, which were superseded by no significant interaction of group by time, $F(2, 52) = 2.720, p = .075, \eta_p^2 = .095$. In the concentrations of plasma cortisol, two-way ANOVA revealed no significant main effects for group, $F(1, 52) = 2.134, p = .156, \eta_p^2 = .039$, and time, $F(2, 52) = 0.027, p = .973, \eta_p^2 = .010$, which were superseded by no significant interaction of group by time, $F(2, 52) = 0.418, p = .661, \eta_p^2 = .016$. These results indicate no significant differences in the changes in blood hormone concentrations between the LST and LN groups.

**Discussion**

This study demonstrates three important findings for participants age 59–76 years: (a) Muscle thickness and strength of the knee extensors and flexors increased after 12 weeks (2-week preparation and 10-week intervention) of low-intensity (50% 1RM) resistance training with slow movement and tonic force generation (LST), (b) strength of the knee extensors and flexors but not muscle thickness of the knee extensors increased after a 12 weeks (2-week preparation and 10-week intervention) of low-intensity (50% 1RM) resistance-exercise training with normal speed (LN), and (c) there were no differences in acute physiological responses to a single bout of exercises, such as changes in blood hormone concentrations and the minimal muscle oxygenation level, between the LST and LN groups.

Kalapotharakos et al. (2004) compared the hypertrophic effect of high-intensity resistance training with that of moderate intensity. They concluded that muscle strength and mass can be improved in older participants with both high- and moderate-intensity resistance training, but high-intensity resistance training can cause greater increases in muscle size and strength. According to their report, moderate-intensity resistance training (60% 1RM) caused a 7.1% increase in the cross-sectional area (CSA) of quadriceps and a 7.9% increase in the CSA of hamstrings, as well as 6.3–13.4% increases in isokinetic knee-extension and -flexion strength, in older individuals (Kalapotharakos et al., 2004). In the current study, the LST intervention caused a 6.5% increase in front muscle thickness, a 6.1% increase in back muscle thickness, and 20.5% increases in both isometric knee-extension and isometric knee-flexion strength. It should be noted that in this study, we measured muscle thickness, the increase in which is theoretically proportional to the square root of the increase in muscle CSA. Thus, the muscle CSA might increase by as much as 10%. Previous studies showed that LST caused significant increases in muscle size and strength, as did traditional high-intensity (80–90% 1RM) resistance training, in young untrained men (Tanimoto & Ishii, 2006; Tanimoto et al., 2008). Therefore, it is possible that the effect of LST is as large as that of traditional high-intensity resistance training, even for older adults.

The current study showed significant increases in all strength measures after both LST and LN training (Table 3). Thus, it can be interpreted that the LN protocol effectively caused an increase in strength, as did LST, while its hypertrophic effect was smaller than that of LST. This is probably because muscle strength is primarily related to neural factors—that is, the ability to recruit motor units—in addition to muscle CSA (Ikai & Fukunaga, 1970). In particular, 1RM strength is influenced by the “learning effect” of repeated exercise bouts (Rutherford & Jones, 1986). Because of the absence of a sedentary control group in this study, an additional study is
needed to examine the contribution of learning effect to strength gain. Taaffe et al. (1996) reported that low-intensity resistance training (40% 1RM) caused a 41.5% gain in 1RM strength in leg exercise. Vincent et al. (2002) also reported that low-intensity resistance training (50% 1RM) increased 1RM strength of knee extension and flexion by 10.8% and 25.3%, respectively. In the current study, an intervention of low-intensity resistance training (LST or LN) caused 7.8–20.1% increases in knee extension and flexion, which is lower than previous reports (Taaffe et al., 1996; Vincent et al., 2002). The variability in strength gain might be attributable to the differences in age of participants, their initial physical activity levels, and exercise regimens. However, to prevent sarcopenia, LST, with its higher possibility to induce muscle hypertrophy, would be more desirable than LN.

In the current study, muscle hypertrophy of both knee extensors and knee flexors was induced only by LST. The primary factors responsible for LST’s effect would be the continuous muscle action (3-s eccentric, 3-s concentric, and 1-s isometric force generation), because the relative intensity and the amount of mechanical work for LST were the same as those for LN. Although the precise mechanisms underlying LST’s chronic effect remain unclear, the suppression of both blood inflow to and outflow within the working muscle due to continuous force generation at >40% maximum voluntary contraction (Bonde-Petersen, Mork, & Nielsen, 1975; Koba et al., 2004) is considered important (Tanimoto & Ishii, 2006; Tanimoto et al., 2008). The acute physiological responses to continuous force generation throughout exercise movement might be related to the effect of the LST intervention (Tanimoto & Ishii, 2006; Tanimoto et al., 2008). Previous studies (Goto et al., 2008; Tanimoto & Ishii, 2006; Tanimoto et al., 2005; Tanimoto et al., 2008) reported that the acute responses to LST in young men have the following characteristics: much lowered peripheral muscle oxygenation level during exercise, elevated peripheral muscle oxygenation level immediately after exercise, increased blood lactate concentration after exercise, and increased circulating anabolic hormones such as growth hormone after exercise, and the magnitude of changes in LST has been shown to be much larger than in LN for all of these factors. However, in the current study, the acute responses to LST in older participants were different from those in young men (Figures 1–3). A possible reason for the discrepancy in the acute responses to LST between old and young participants is that the current LST protocol would not cause a sufficient restriction of muscle blood flow. Muscle atrophy with aging may attenuate contraction-associated increases in intramuscular pressure, thereby causing an insufficient restriction of muscle blood flow during LST. It has been also reported that arterial stiffness increases with aging (Vaitkevicius et al., 1993), and this may be a factor for the attenuation of contraction-induced reduction in muscle blood flow. The attenuated restriction of muscle blood flow during contraction may account for the lack of a significant difference in the minimal oxygenation level between LST and LN (Figure 2). It is also possible that the smaller decrease in muscle oxygenation level during LST causes smaller accumulation of metabolic subproducts such as lactate and proton, which has been shown to be related to the hypophyseal secretion of growth hormone (Kraemer & Ratamess, 2005; Takarada et al., 2000). In addition, preferential atrophy of Type II muscle fibers with aging (Lexell, 1995; Lexell, Taylor, & Sjostrom, 1988) may influence lower blood lactate concentration during LST in older participants, because lactate is mainly produced in Type II muscle fibers (Brooks, 2000). However, the interpretations of acute physiological responses to a single bout of exercise are associated with
several limitations in this study. One limitation is that blood lactate concentration was measured shortly before the end of the intervention (at 7–9 weeks). Although adaptations to exercise might occur, there was a significant difference between LST and LN. Another limitation is that muscle oxygenation level and blood hormone concentrations were measured 1–6 weeks after the intervention period. Thus, they might have been subject to the effect of detraining.

This study demonstrated that the LST intervention effectively increased muscle size and strength in older participants without the acute responses that have been observed in young participants (Goto et al., 2008; Tanimoto & Ishii, 2006; Tanimoto et al., 2005; Tanimoto et al., 2008). Although the exact mechanism remains unclear, a long contraction time and thus large mechanical impulse (force–time integral) may be related to the muscle hypertrophy and strength gain. In this study, we matched the intensity of exercise (50% 1RM) and the work volume (8 repetitions × 3 sets) to make the LST and LN protocols different only with respect to exercise movement. However, total contraction time in LST was much longer than that in LN (7 s × 8 repetitions × 3 sets = 168 s for LST, and 2 s × 8 repetitions × 3 sets = 48 s for LN). Therefore, it is possible that LN is also effective in increasing muscle size if the total contraction time is the same as that for LST. In fact, low-intensity resistance training with a long total contraction time has been reported to significantly increase muscle size and strength (Holm et al., 2008; Westcott et al., 2001). However, increasing the total contraction time in LN is necessarily associated with an increase in work volume and resulting metabolic and cardiovascular stress. Therefore, we believe that LST is more desirable for older adults, in particular when their physical strength is exceptionally low. Research is needed comparing both acute and chronic effects between LST and LN with the same intensity and total contraction time.

In conclusion, LST is effective in increasing muscle size and strength, even for older individuals. Since LST exercise is low intensity and bears lower risk for orthopedic injury and cardiac events (Tanimoto & Ishii, 2006), this should be useful as a countermeasure against sarcopenia. However, the exact mechanisms underlying the muscle-hypertrophic effect of LST in older participants still remain unclear and need further elucidation.

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References

Exercise With Slow Movement and Tonic Force


